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The Issue in Perspective

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GROUNDWATER QUALITY PROTECTION: THE ISSUE IN PERSPECTIVE

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ABSTRACT. The importance of protecting groundwater resources cannot be overstated, and many people throughout the world seem anxious to physically and financially support a rational program to this end. Public complacency regarding the quality of groundwater was destroyed with headline-grabbing incidents of pollution such as Love Canal, Valley of the Drums, and Times Beach. Contrary to earlier popular belief, the soil mantle has been shown to be ineffective in cleansing certain pollutants from the water flowing through it.

The legislative basis for developing and implementing broad groundwater quality protection programs exists, although it is dispersed in a variety of pieces of legislation. Such programs presuppose the existence of the scientific knowledge necessary to produce viable and effective results from its implementation. This article addresses the research needed for accumulation of this information.

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POLLUTANTS THREATEN GROUNDWATER

The issue of groundwater quality protection is before the nation and Congress. Accounts of contamination incidents are carried in many of our major metropolitan newspapers and national news magazines. In recent months, television news cov-

erage of groundwater pollution has been on the rise; several documentaries on the occurrence, movement, and the pollution of groundwater have been broadcast nationally. The list of contaminated sites resulting from past waste disposal practices seems to be increasing at an alarming rate. The U.S. Environmental Protection Agency (EPA) has identified 546 hazardous sites to date as candidates for remedial action. Four hundred of these pose some threat to underground sources of drinking water. Every year billions of tons of solid waste are discarded in the United States. These wastes range in nature from common household trash to complex materials in industrial wastes, sewage sludge, agricultural residues, mining refuse, and pathological wastes from institutions such as hospitals and laboratories. Each year, industries alone treat 5,000 billion gallons of effluent. One thousand seven hundred (1,700) billion gallons of this go into oxidation ponds or lagoons for treatment. Based on estimated leakage rates, 100 billion gallons will leave the ponds and lagoons each year and enter the groundwater system. Of the estimated 18,500 municipal landfills in the United States in 1977, most were open dumps or were poorly sited (U.S. EPA, 1977). The U.S. EPA estimated that in 1980 57 million metric tons of the

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nation's total wasteload could be classified as hazardous. Unfortunately, many of the dangerous materials that we have "thrown away" over recent decades have persisted in the environment, making household words of "Love Canal," "Valley of the Drums," and "Times Beach." These incidents are not unique. There are hundreds of documented cases of environmental damage resulting from improper disposal or management of hazardous wastes. The vast majority of these cases involve pollution of groundwater, the source of drinking water for over half of the U.S. population (U.S. EPA, 1980). Despite heightened public concern and an advanced body of scientific knowledge relating to the occurrence and movement of groundwater, it probably remains the most misunderstood of our major natural resources by the general public who often envision underground streams or large underground reservoirs similar to surface impoundments.

It is apparent that government at all levels is anxious to address the issue of groundwater pollution and groundwater quality protection. It should also be clear that an effective program for groundwater protection must include not only a workable legal framework for administration, but also a sound scientific understanding of the occurrence and movement of groundwater and the behavior of contaminants in the subsurface environment. The following review may help place the issues in proper perspective.

A VITAL RESOURCE

Groundwater is a valuable resource because of its quality and availability. It is available in most locations in quantities large enough to provide for domestic needs; 50 percent of the population of the United States depends on groundwater for drinking water sources. In fact, 90 percent of our rural population depends on groundwater, and it supplies 25 percent of all the fresh water used for all purposes in the United States (Josephson, 1980). Our groundwater resources are enormous. This country's fresh groundwater supply, within one-half mile of the earth's surface, constitutes about 150 trillion cubic meters or roughly four times the volume of the Great Lakes (Burmester, 1982). Groundwater is a reliable resource not subject to extremes in temperature or quality fluctuations, and it is buffered from floods and droughts which affect surface supplies. Development of groundwater has little effect on land use and can usually be accomplished at relatively low costs compared to surface supplies (U.S. EPA, 1977).

This expansive nature of groundwater is paradoxical in terms of its ability to meet water supply requirements over long periods of time. On the one hand, groundwater is available in various quantities nearly everywhere; on the other hand, it is subject to contamination from a host of sources including surface impoundments, landfills, agriculture, leaks and spills, land disposal of wastes, septic tanks, mining, petroleum and gas production and storage, underground injection of wastes, and other miscellaneous activities.

The subsurface environment is a complex system subject to extensive physical, chemical, and biological variations within small vertical or horizontal distances. This complexity is accentuated profoundly on a macro scale in terms of the multiplicity of materials comprising aquifer and soil systems. Clays, sands, silts, loams, and the various rocks and organic residues which constitute the subsurface matrix each play a unique role in water supply and waste disposal systems.

An extended period of time is usually required for movement of a pollutant from the land surface through the soil profile to underlying groundwater. The overland movement of pollutants from a source to a stream or lake may require only hours or at the most a few days, but in the subsurface, the movement to the groundwater may take weeks or, in some cases, even years. This transport time depends on many variables, including rainfall occurrence, intensity and duration; subsurface physical properties that control percolation rates; and the nature of interactions between the pollutant and the subsurface materials. Thus, activities that introduce chemicals to the land surface may continue for many years before the pollutants are detected in the groundwater. In fact, in some cases, the pollutant sources may be gone and forgotten before the groundwater problems become apparent.

Because of the protracted effects of contamination and problems of accessibility, the restoration of underground water quality is difficult and expensive, with costs generally exceeding the short-term value of the resource as compared to the costs of alternatives. For this reason, it is widely agreed that the most viable approach to groundwater quality protection is one of prevention rather than cure (Kerns, 1977).

While the existence of our groundwater contamination problems cannot be denied, the very nature of the groundwater environment and the extremely slow rate of movement of groundwater tend to limit the spread of pollutants in the subsurface and ameliorate the severity of the problem. Although evidence of groundwater contam-

ination is found in many places, the volume of groundwater contaminated is small compared to the size of the resource. Available estimates suggest that only a few percent of available groundwater resources, at most, have been contaminated. As would be expected, however, most of the polluted groundwater occurs in areas of high population density and high demand for the resource. Aquifers already contaminated may, however, remain so for a long period because practical technology for purifying them has only recently been under development.

LEGISLATION PROTECTING GROUNDWATER

Historically, environmental legislation has been directed at tightening controls on that pollution which has directly assaulted our senses. Trash floating in harbors and rivers causing obstruction to navigation inspired the first piece of federal environmental legislation—the Rivers and Harbors Act of 1899. While this initial act is still in effect and has served as the basis for waste discharge permits issued by the Corps of Engineers and EPA, federal authority for addressing groundwater quality problems is now embodied in at least eight statutes. Ironically, much of the environmental legislation of the past, and the present, may actually have the effect of shifting pollution loads from the air, rivers, and oceans to the soil and ultimately to groundwater (U.S. EPA, 1977).

CWA

The Water Pollution Control Act of 1956 was amended over the years, evolving into the Federal Water Pollution Control Act in 1972 and the Clean Water Act in 1977. This act is aimed primarily at pollution control of navigable waters with the eventual goal of eliminating waste discharges to these systems. The Clean Water Act provides for state water quality management programs that may address groundwater.

NEPA

The National Environmental Policy Act of 1970 requires that Environmental Impact Statements be prepared for projects that might have significant adverse effects on the environment, including groundwater.

SDWA

Groundwater protection under the Safe Drinking Water Act is implemented through drinking water regulations, underground injection control regulations, and the sole source aquifer program.

At present there are drinking water standards

which establish maximum contaminant levels for ten inorganic chemicals, ten organic chemicals (including six pesticides), microbiological contaminants, radionuclides, and other contaminants found in groundwater. In addition, there is a four-phase plan for promulgation of new regulations.

In the underground injection control program, underground injection of materials that pose a threat to groundwater is regulated. This program ensures that injection well activities do not endanger present and future sources of drinking water.

Lastly, the sole source aquifer program permits citizens to petition EPA for designation of an area as a sole source if it is a principal water supply. To date, 11 aquifers have been designated, and an additional 22 petitions are being reviewed. This designation provides for EPA review of all federally funded projects that may affect the quality of groundwater in a sole source aquifer.

TSCA

The Toxic Substances Control Act addresses groundwater contamination issues under three sections. Under Section 4, the EPA may require testing of chemical substances to determine whether they pose unreasonable risks to human health or the environment. Under Section 5, manufacturers of chemicals are required to notify the agency before beginning production of new chemicals, or before beginning production of a chemical for a significant new use. Under Section 6, the agency can take various regulatory actions against chemicals which present an unreasonable risk to human health and the environment.

RCRA

Under Subtitle C of the Resource Conservation and Recovery Act, EPA has promulgated regulations which provide "cradle to grave" management of hazardous waste. Operators of land disposal facilities (approximately 1,400) are required to monitor for potential groundwater contamination. New facilities must have underliners and leachate collection systems. Corrective action is required in the event of groundwater contamination at permitted facilities.

SMCRA

The Surface Mining Control and Reclamation Act of 1977 has provisions aimed at the prevention of chemical contamination and hydrological disruption of groundwater.

FIFRA

The Federal Insecticide, Fungicide, and Rodenticide Act is a licensing statute which permits EPA

to restrict the use of hazardous pesticides and to cancel or suspend the registrations of pesticides that pose the risk of unreasonable adverse effects to humans or the environment. FIFRA gives the agency significant discretion in dealing with possible contamination of groundwater by pesticides.

CERCLA

In 1980, Congress enacted the Comprehensive Environmental Response, Compensation, and Liability Act ("Superfund") which authorizes governmental responses to spills of hazardous substances as well as cleanup of abandoned hazardous waste sites. The act defines "environment" to include groundwater and establishes a \$1.6 billion trust fund to finance governmental responses to releases or threats of releases of hazardous substances that may harm human health or the environment.

State Legislation

State attention to groundwater quality, like federal attention, has generally had a low priority compared to concern for surface water quality. This is further complicated by the complexities and diversity of groundwater ownership from one part of the country to another.

The protection of groundwater quality in most states is gained from statutes dealing with surface water which generally are based on public health (U.S. EPA, 1977). Land-use regulations are also used to protect groundwater quality by locating waste sources, such as lagoons and solid waste facilities, in areas to minimize the pollution potential.

Construction regulations are often used in a secondary manner to protect groundwater. For example, water wells are constructed primarily to prevent contamination of the well; little thought is given to protecting the area's groundwater. Septic tank regulations are aimed specifically at controlling surface discharges, disease, and nuisance in much the same way that landfills are designed to prevent smoke, odors, rodents, and unsightliness.

PREVENTION THE BEST PROTECTION

The only technically or economically viable option now available for protection of groundwater quality on a broad scale is prevention of contamination (Kerns, 1977).

One simple approach would be to ban from the recharge zone all land-use practices that could contribute pollutants to the aquifer. While this might work in some instances, it simply cannot be adopted totally in any practical way. The com-

munity of man will continue to produce waste products as a result of those activities deemed necessary to support a contemporary standard of living, and those wastes must be managed with considerable thought given to economics.

Some wastes, due to their high inherent toxicity, should probably not be disposed of on the land. For these, incineration, eternal encapsulation, or deep well injection offer the principal management options. For other less hazardous chemicals, nature itself can provide economical treatment alternatives to render them environmentally acceptable. The key is to understand the natural physical, chemical, and biological processes which control the transport and transformation of contaminants in the subsurface so that we can manage the system and utilize its natural assimilative capacity in order to protect groundwater effectively without unnecessarily restricting other land use activities.

RESEARCH REQUIRED

A research strategy designed to provide the technical information required by a viable groundwater protection program has been developed over the past few years by the U.S. EPA and other public and private organizations.

This strategy requires developing the scientific knowledge of pollutant behavior in the subsurface to permit intelligent management of groundwater resources. Management considerations include the ability to identify, evaluate, and control potential sources of groundwater contamination; to assess the risks and impacts associated with emergency spill situations and other contamination events; and to take remedial action in the restoration of groundwater quality.

SUBSURFACE PROCESSES

The processes that govern the behavior of pollutants in the subsurface can be divided for research purposes into three major areas: hydrologic, abiotic, and biotic. These processes will act to influence: the movement of water, the primary vehicle for subsurface pollutant movement; the physical and chemical interactions that will cause pollutants to move at rates different from those of the water; and chemical or microbial alterations that will remove pollutants from the subsurface or render them to insoluble constituents at the surface matrix. The elucidation of the importance and magnitude of the various mechanisms functioning in the three process areas will ultimately provide the knowledge to integrate the influences of these

processes into a singular understanding of pollutant behavior in the subsurface. Research under each of these process areas is organized into a series of tasks focusing on methods development, subsurface characterization, pollutant attenuation, process kinetics, field application, and mathematical model development and application.

Hydrologic Processes

Efforts in hydrologic processes are primarily directed toward two aspects: (1) the influence of the physical and chemical features of the subsurface on the movement of fluids and accompanying contaminants through it, and (2) mathematical descriptions of the processes that control this movement (Keeley, 1982). The results of this research will be used to predict the movement of contaminants so that groundwater monitoring procedures can be developed.

Abiotic Processes

The abiotic processes of primary concern in the subsurface environment are sorption/partitioning and chemical degradation. Emphasis to date has been on the sorption process. Gaining a predictive understanding of the sorbate, sorbent, and solution characteristics that affect the rate and degree of sorption will permit refinement of models describing the transport and fate of pollutants in the subsurface.

Biotic Processes

Research efforts in the biotic processes category are focused on developing necessary information to predict the transport, fate, and impact of pollutants in the subsurface and to develop control and remedial technology for groundwater quality. Considerable progress has been made in recent years in developing methods for obtaining uncontaminated samples, in developing new techniques and procedures for characterizing subsurface biota, and in developing technology for determining how biological processes affect pollutant transport and fate (Scalf et al., 1981).

Current information indicates that the deeper subsurface environment is not sterile and that there may be considerable spatial variation in microbial populations both qualitatively and quantitatively (Wilson and McNabb, 1983). These conclusions, however, are based on a very limited number of studies. Far more information on the distribution, density, and nature of organisms in the subsurface, both above and below the water table, is needed. Future studies should emphasize correlating the occurrence and activities of organisms with the geological and mineralogical prop-

erties and the environmental conditions of the subsurface regions where the organisms exist.

At present little is known about biodegradation of organic pollutants in the deeper subsurfaces. A limited amount of pollutant biodegradation research has been done using the indigenous flora of the subsurface and foreign pollutants; virtually no work has been accomplished *in situ* (Wilson et al., 1983). These results have indicated that the potential for significant biodegradation of a number of compounds exists. However, the question of the degree to which these reactions will proceed in the subsurface has not been answered. The limitations have not been clearly defined to be either thermodynamic or kinetic, nor has the extent of adaptation and co-metabolism been investigated in detail. Very little is known concerning degradation byproducts or whether degradation processes can be manipulated.

Little is known concerning environmental conditions in subsurface habitats and the effect such conditions have on biological activity and the biotic transformation of pollutants (McNabb and Dunlap, 1974). Important factors governing the extent and/or nature of biological activity include the concentration and utility of electron acceptors; the concentration and availability of essential nutrients; the oxidation-reduction potential; the pH; the ionic composition; the availability of water; the temperature; the hydrostatic pressure; the nature of solid phase; and the nature of the pore space. All of these factors interact to influence the activity of organisms in the subsurface.

Biodegradability and the associated kinetic relationships must be determined prior to development and use of mathematical models for predicting the movement and fate of pollutants in the subsurface environment. Volatilization and sorption should be determined to predict biodegradation, since a mass balance is required. Reaction kinetics should be determined for modeling. Studies are required to determine the effect of concentration of pollutant in the rate law for transformation; the effect of concentration of pollutant on the density of microbes active against that pollutant; and the correlation between the rate of transformation of the pollutant and the density of viable microbes, or the concentration of some biochemical constituent of the microbes used as an indicator of biomass or nutritional state.

In order to use laboratory and field information about subsurface biotic reactions to predict the fate of pollutants, mathematical submodels that describe the kinetics of biological transformations in the subsurface must be developed, which can be incorporated into more sophisticated mass trans-

port models describing water movement and abiotic attenuation of pollutants. Successful development of a viable biotic processes submodel will depend upon the determination of biotransformation kinetic information. Current mass transport models are deficient in handling biotic processes (Enfield et al., 1982).

Expanded knowledge of pollutant behavior in the subsurface environment is fundamental if we are to take effective action to prevent or limit groundwater pollution or to rehabilitate already contaminated systems. The dearth of knowledge that stems from previous public disinterest in groundwater pollution problems makes the task both arduous and expensive. To quote T. S. Eliot, "The fact that a problem will certainly take a long time to solve, and that it will demand the attention of many minds for several generations, is no justification for postponing the study" (Eliot, 1949).

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